

The Commission's proposed band plan allocates 1000 MHz of spectrum to terrestrial services, which would be available for use by both LMDS and point-to-point microwave services. The Fixed Point-to-Point Communications Section, Network Equipment Division of the Telecommunications Industry Association ("TIA") has objected to this plan, arguing instead that point-to-point microwave services should be given a co-primary allocation in 500 MHz of the spectrum allocated to GSO FSS satellite uses.<sup>31/</sup>

**A. The Commission Has Proposed Reasonable Ways To Accommodate The Fixed Point-To-Point Service**

TIA's objections are groundless. First, TIA argues that its views have not been adequately considered by the Commission.<sup>32/</sup> Through sleight of hand, TIA turns the Commission's refusal to adopt the fixed microwave industry's proposals into a complete disregard of its submissions. It is simply wrong that the fixed microwave industry's proposals have not been considered by the Commission. Although a Notice of Proposed Rulemaking is clearly not the final expression of the Commission's rationale behind its decisionmaking, the Commission has specifically noted that it has taken into account the presentations made by Harris and Digital, including the channelization proposal contained in their rulemaking petition.<sup>33/</sup> TIA tries to make much of the fact that the Commission has not proposed to adopt these recommendations, but the Commission has not proposed to adopt

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<sup>31/</sup> See Comments of TIA at 14-18. This co-primary allocation is proposed for the 28.35-28.6 GHz and 29.25-29.5 GHz bands, each of which has been proposed under the current band plan for primary use by the GSO FSS.

<sup>32/</sup> Comments of TIA at 4-9.

<sup>33/</sup> See Third Notice at ¶ 51-52.

any other party's proposed band plan either. Instead, it has offered a compromise solution. No party got what it wanted.

Second, TIA attacks the proposed band plan as "arbitrary and capricious."<sup>34/</sup> The fact that the Commission has tentatively decided that it will not adopt channelization or dedicate part of the band to private fixed microwave carriers does not mean that the Commission's decision is unreasoned. In fact, the Commission has preliminarily indicated that the public interest would be better served by the point-to-multipoint technologies rather than point-to-point uses in the spectrum it has allocated for terrestrial uses.<sup>35/</sup> It has also indicated that spectrum in other bands is available for fixed terrestrial uses.<sup>36/</sup> These are the very types of choices that the Commission makes in allocation proceedings.

Third, TIA's objections rest upon the licensing procedures for terrestrial services, not the ultimate allocation between terrestrial and satellite. TIA's needs could be met through the adoption of appropriate rules for licensing point-to-point systems in the "LMDS" band.<sup>37/</sup> TIA apparently recognizes this, but rejects each of the Commission's proposed methods for licensing this spectrum to point-to-point services.<sup>38/</sup> And although

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<sup>34/</sup> Comments of TIA at 9-12.

<sup>35/</sup> Third Notice at ¶ 52.

<sup>36/</sup> *Id.* The record in this proceeding, which should be summarized by the Commission in its Order promulgating the allocations in the 28 GHz band, indicates "overall rational support" for a decision that the demand for fixed terrestrial services can be satisfied in other bands. *See generally Center for Auto Safety v. Peck*, 751 F.2d 1336, 1370 (D.C. Cir. 1985).

<sup>37/</sup> Third Notice at ¶ 53.

<sup>38/</sup> Comments of TIA at 12-14.

TIA complains about certain definitional problems in the proposed rules,<sup>39/</sup> it offers no suggestions on how to address its concerns. The Commission has carefully balanced all of the competing needs in this proceeding and has concluded that all terrestrial uses of the 28 GHz band can be accommodated in the 1000 MHz that will be set aside for LMDS. TIA's objections should be resolved through the adoption of rules that will allow licensing of the terrestrial spectrum to both LMDS and point-to-point interests.<sup>40/</sup>

**B. Fixed Point-to-Point Services Cannot Be Given Co-Primary Access to GSO FSS Spectrum**

Hughes strongly opposes TIA's proposal to allow point-to-point services to operate on a co-primary basis in 500 MHz of the 1000 MHz that is proposed to be set aside for GSO FSS. The record in this proceeding is clear that the GSO FSS satellite industry requires access to a full 1000 MHz for use by ubiquitously deployed VSATs.<sup>41/</sup> In making the determination that the GSO FSS should not have to coordinate these VSATS with

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<sup>39/</sup> *Id.* at 13 & n. 11.

<sup>40/</sup> TIA's claim that point-to-point users cannot obtain 28 GHz spectrum allocated for terrestrial uses because "applications for intermediate microwave links are, unlike proposed LMDS services, not subject to auction" is wrong. *See* Comments of TIA at 13. The Commission evaluates the classes of licenses and permits for which the spectrum will be used, not individual licenses, to determine whether the principal use of the spectrum is for subscriber service and therefore subject to competitive bidding. *See In re Implementation of Section 309(j) of the Communications Act -- Competitive Bidding*, 9 F.C.C. Rcd 2348, 2354 (1994). If a majority of the spectrum is to be used for subscriber services, then auctions are permissible. *Id.* The Commission has reached a conclusion that the primary use of the 28 GHz band allocated for terrestrial uses will be used for subscriber services. Notice at ¶ 130. Point-to-point services are subsumed within that conclusion and their licensing at 28 GHz would therefore be subject to competitive bidding.

<sup>41/</sup> There is no basis for TRW's claim that the Commission "appears not to quarrel with TRW's assertion that 850 MHz of spectrum is sufficient for the GSO/FSS." *See* Comments of TRW at 37. To the contrary, the Commission listed several reasons why the GSO FSS needs access to 1000 MHz. *See, e.g.*, Third Notice at ¶¶ 54-55.

terrestrial services in the 28 GHz band, the Commission has carefully balanced the burdens that the GSO FSS industry is being asked to bear as a result of this proceeding.

Under the current band plan, the GSO FSS will be required to share spectrum with NGSO MSS feeder links, and will lose access on a primary basis to 1.5 GHz of the 28 GHz band that was previously available to it and available to help solve terrestrial coordination problems. If GSO FSS operators are required also to coordinate their operations with a terrestrial service, use of their 1000 MHz of remaining spectrum for satellite services would be even further constrained. In particular, the reduction in the amount of spectrum available to a GSO FSS operator would significantly hinder its flexibility in a coordination process with a point-to-point system. Under the prior 2.5 GHz allocation, GSO FSS operators had access to a wide range of the 28 GHz band to solve coordination problems; under the current plan, they have nowhere to go. The flexibility that existed before to make GSO FSS/point-to-point sharing possible on a co-primary is simply gone now. There is no basis for believing that co-primary GSO FSS and point-to-point use of the same band is feasible any longer. <sup>42/</sup>

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<sup>42/</sup> TIA mischaracterizes Hughes's position when it implies that Hughes supported a proposal permitting the co-primary sharing of a portion of the 28 GHz band by fixed microwave services and the GSO FSS. See TIA Comments at 17. Hughes previously recognized the problems identified above with the point-to-point service and therefore suggested that the fixed microwave service might be allowed to operate on a *secondary* basis to the GSO FSS in portions of the 28 GHz band, but it never proposed a co-primary allocation for the fixed microwave service. See Further Comments of Hughes, The Boeing Company, Teledesic Corporation and Teledesic Corporation, filed May 12, 1995.

To the extent that the Commission nonetheless seeks additional spectrum for the point-to-point industry, Hughes recommends that the Commission consider the 28.6-29.1 GHz band. The high elevation angles proposed for the Teledesic system (40 degrees or more) make that band particularly well-suited for sharing with terrestrial services. Moreover, the existence of only one satellite operator in that band should

## **VI. OTHER ISSUES**

### **A. It Is Premature to Auction Satellite Spectrum**

28 GHz satellite proponents are unanimous on at least one point: there is no need to consider auctioning 28 GHz satellite spectrum.<sup>43/</sup> As the commenters clearly indicate, the Commission must first employ its traditional licensing procedures, which are likely to eliminate any mutual exclusivity among the existing satellite applicants in the 28 GHz band. Only if there are insufficient orbital locations for all qualified applicants should the Commission revisit the propriety of using auctions to award satellite licenses.

### **B. There is No Basis for Accommodating LMDS in the FSS Bands**

Both the Commission and the Negotiated Rulemaking Committee have recognized that LMDS and GSO FSS cannot share the same spectrum due to the interference between LMDS stations and the ubiquitous FSS user antennas.<sup>44/</sup> For over two years, the parties to this proceeding have been unable to find any realistic technical basis for LMDS/FSS sharing, and no party has yet responded to the studies submitted by MITRE Corporation and NASA, which also concluded that sharing was not feasible.

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facilitate coordination with terrestrial services.

<sup>43/</sup> See, e.g., Comments of Motorola at 19-24; Comments of TRW at 28-33; Comments of Loral Aerospace Holdings, Inc. at 5-7; Comments of Teledesic at 24-31; Comments of GE Americom at 22-25.

<sup>44/</sup> See Third Notice at ¶¶ 39, 43 ("Based on the existing record, we tentatively conclude that co-frequency sharing between NGSO/FSS or GSO/FSS and LMDS systems is not feasible at this time."); see also Comments of Comtech Associates, Inc. at ¶ 3 ("co-frequency sharing between NGSO/FSS or GSO/FSS systems and LMDS systems is not feasible").

LMDS proponents nevertheless advocate that LMDS/FSS sharing is possible and urge the Commission to keep open the chance for licensing LMDS in the FSS bands.<sup>45/</sup> The Commission should not be swayed by the eleventh-hour appeals that sharing between LMDS and GSO FSS may be feasible, or is simply a matter of "motivation" of the parties.<sup>46/</sup> Not one of these parties has submitted any credible evidence that contradicts the record in this proceeding. Andrew Corporation's plan for its "miracle antenna" that purportedly would enable LMDS and GSO FSS to share spectrum on a co-primary basis is completely unproven.<sup>47/</sup> The sparse technical data submitted with Andrew's Comments provides no support for its conclusion that LMDS and GSO FSS can share the spectrum. There simply is no basis for changing the Commission's tentative conclusion that LMDS and FSS should *not* be provided co-primary status in the same band.<sup>48/</sup>

The Commission should therefore decline the proposals of some LMDS proponents to "leave the door open" for co-frequency sharing between LMDS and FSS. The time has come for the Commission to make final allocation decisions.<sup>49/</sup> GSO FSS

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<sup>45/</sup> See, e.g., Comments of Bell Atlantic at 3-4 ("Although the FCC tentatively concluded that the existing record does not establish the feasibility of such sharing, Bell Atlantic continues to believe that co-frequency sharing is feasible . . ."); Comments of CellularVision at 4-5 ("CellularVision believes that if all parties are sufficiently motivated, mutually acceptable regulations for co-frequency sharing can be developed"); Comments of Endgate Corporation at 1.

<sup>46/</sup> See Comments of CellularVision at 5.

<sup>47/</sup> See Comments of Andrew Corporation.

<sup>48/</sup> Given the practical difficulties of requiring entrenched LMDS uses to accept interference once GSO FSS systems are deployed, the Commission should not consider even a secondary allocation for LMDS in the GSO FSS bands.

<sup>49/</sup> If, in the future, sharing between LMDS and GSO FSS appears to be feasible, interested parties can petition the Commission for a new rulemaking to address that

operators must turn their attention to building satellite systems, and they need the certainty that their systems will be able to operate freely in this available 1000 MHz of spectrum without encountering interference problems with the LMDS service.<sup>50/</sup>

**C. The Commission Should Not Adopt a Band Plan Until After WRC-95**

With WRC-95 preparations well under way, and the conference rapidly approaching, the commenting parties are in near-unanimous agreement that the resolution of this proceeding should await the conclusion of WRC-95. Hughes firmly agrees with TRW that the Commission should forego any decisions on the 28 GHz until after the conference,<sup>51/</sup> and with GE Americom that the Commission should solicit "supplemental comments" afterward to address how the results of WRC-95 should be incorporated into this proceeding.<sup>52/</sup>

The complexities of the band plan created by the interrelationships between the services that the Commission proposes to accommodate make the band plan impossible to finalize prior to the determinations of WRC-95. Hughes reiterates its strong support for postponing the resolution of this proceeding until the outcome of WRC-95.

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question.

<sup>50/</sup> On another matter, Motorola argues that the Commission should adopt a "stringent financial qualification" requirement for Ka band FSS systems. Comments of Motorola at 24. While Hughes does not dispute the need for the Commission to enforce its financial and other qualification rules, it is important to note that financial qualification rules *already* exist for Ka band and all other FSS systems. See 47 C.F.R. § 25.114(c)(18); Establishing of Satellite Systems Providing International Communications, 101 F.C.C. 2d 1046 (1985) *recon.* 61 Rad. Reg. 2d 649 (1986), *further recon.* 1 F.C.C. Rcd. 439 (1986).

<sup>51/</sup> See, e.g., Comments of TRW at 33-34.

<sup>52/</sup> See, e.g., Comments of GE Americom at 20.

## **VII. CONCLUSION**

The key to the Commission's band plan is resolving the inability of the presently proposed NGSO MSS feeder link systems and the GSO FSS to share 250 MHz of spectrum. The Comments in the proceeding demonstrate that it is not feasible for NGSO MSS feeder links and the GSO FSS to share spectrum in the 29.25-29.5 GHz band on a "first-come, first-served" basis as proposed by the Commission. It is also apparent that the only feasible alternatives to the Commission's proposal are those proposed by Hughes: Unless the Commission identifies and implements reasonable NGSO/GSO sharing criteria, it should either accommodate MSS feeder links on a reverse band basis or modify the proposed band plan as Hughes has suggested to avoid overlaps between NGSO MSS feeder link and GSO FSS spectrum. The Commission should disregard Motorola's suggested solution as vague and ill-conceived and TRW's proposals as too uncertain. Hughes's proposals would free the 29.25-29.5 GHz band from the conflicting demands that now exist without adversely affecting any service.

The Commission must also ensure that adequate spectrum remains available to the GSO FSS in the 17.7-20.2 GHz companion downlink band to the 28 GHz uplink band. Given the constraints already placed upon the GSO FSS in the downlink band by NGSO MSS feeder links and existing Space Science power limits, the Commission should continue to allow GSO FSS operators the flexibility to choose the downlink spectrum that best meets their system needs. The Commission should not mandate an artificial downlink "band pairing."

The pleas of the LMDS proponents to leave the door open for future LMDS allocations in GSO FSS spectrum should be dismissed out of hand, as should the complaints


of the terrestrial point-to-point microwave services. The Commission has long considered both of these issues, and has come to reasoned and well-supported tentative conclusions for accommodating these services.

The Commission should not subject satellite services to competitive bidding unless its traditional processing procedures have failed to eliminate mutual exclusivity between applicants. In that case, the Commission must carefully consider whether competitive bidding would be in the public interest.

Finally, the Commission should defer any decision on the band plan until after WRC-95.

Respectfully submitted,

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**Use of IRIDIUM Site Diversity and APC  
To Mitigate Interference Between  
IRIDIUM and SPACEWAY Networks**

**Hughes Space and Communications Company**

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**Abstract:**

This paper describes a technique that can be used to mitigate interference between the SPACEWAY Ka-band system and feeder links of the IRIDIUM system if they were to use the same spectrum in the same direction of propagation. This technique is that of site diversity, combined with the judicious use of the available APC reserve power in IRIDIUM transmitters. The technique is essentially to determine on a pre-scheduled basis which of the three IRIDIUM earth stations in a three-station complex to use for any given pass of an IRIDIUM satellite. The application of this technique would be able to constrain the interference into both networks to acceptable levels during a potential transient interference "hit" involving a GSO and a LEO satellite. The technique can be used in an environment of closely packed satellites on the GSO, and would retain the option of adequately protecting IRIDIUM links during intermittent rain outage.

The technique can be applied where the GSO satellite has an elevation angle not less than about 25°. At higher latitudes where lower elevation angles may be experienced, the technique can be complemented by a spacecraft-diversity technique to accomplish the same objective, again on a scheduled basis, without requiring the use of any additional IRIDIUM spacecraft above the 66 used in the IRIDIUM constellation.

# **Use of IRIDIUM Site Diversity and APC To Mitigate Interference Between IRIDIUM and SPACEWAY Networks**

**Hughes Space and Communications Company**

## **1.0 Introduction**

The designers of both the IRIDIUM and the SPACEWAY satellite networks are considering use of Ka-band (30/20 GHz) spectrum in the same directions of propagation. If special measures were not taken to reduce or avoid it, there would be harmful transient interference between the two networks. This paper describes one such measure that can easily be put into practice using equipment being implemented for other complementary purposes. That measure is the prudent choice of earth stations within a planned IRIDIUM earth-station complex, on a scheduled basis, to reduce the interference levels of both networks to workable levels.

To examine this technique in an organized way, the assumed characteristics of the two networks are reviewed in **Section 2** of the paper. These descriptions are not meant to be an exhaustive review of the characteristics of the two networks in any way, but only to serve as an understanding of the characteristics of the two networks used in the analysis to follow.

The characteristics of the noise in each of the two networks and the interference between the two networks is then reviewed briefly in **Section 3** of the paper, as a base upon which to explore the possibilities of earth station site diversity as a technique to improve that interference significantly in both networks. The criteria used to measure that interference is the carrier to noise plus interference ratio in each of the two networks. Worst-case interference when the two satellites are in their worst relative positions (from an interference perspective) are considered, together with estimates of the duration of the interference events.

In **Section 4** the possibility of using IRIDIUM earth station site diversity is explored. IRIDIUM earth stations are considered in this role because there are relatively few of them in number, because they are planned to significantly larger antenna diameters than SPACEWAY earth stations, and because an IRIDIUM earth-station complex is planned for complementary reasons to be comprised of three earth stations separated by tens of nautical miles.

In **Section 5** the operational aspects of utilizing this interference-mitigation technique are taken into account. These aspects consider the use of automatic power control (APC) for mitigation of both interference rain attenuation, consider the ability to pre-schedule which earth station of an IRIDIUM earth-station complex to use for a given pass of a IRIDIUM satellite, and consider other factors that may be considered significant in the regular use of APC within the IRIDIUM system.

These findings are summarized in **Section 6**, and conclusions drawn from those results. A suggestion is made on how the technique can be used to increase the utilization of the limited available spectrum resource in Ka-band.

## **2.0 Characteristics of the IRIDIUM and SPACEWAY Systems, from the Perspective of the Potential for the Sharing of Spectrum Between Them**

Salient features of the two networks are described briefly in this section. Detailed information, a complete listing of the parameters and their numerical values used in the analysis, can be found in the attached **Annex A** to this paper. This information is not intended for any other purpose than providing the necessary data-base upon which to examine the transient interference between the two networks and the possible use of site diversity as a measure to mitigate that interference.

### **2.1 Salient Features of the SPACEWAY System**

The SPACEWAY satellite system is a fixed-satellite system to be placed in the geostationary orbit (GSO). To serve CONUS such satellites are planned to be located in the GSO at 99° W and 101° W. The nominal minimum elevation angle of Earth stations served from these satellites is 30°. The satellite has multiple 1° to 1.1° beams covering the service area.

QPSK traffic at rates from 384 kbps to 1,544 kbps in the uplink is re-processed in the satellite, thereby avoiding the addition of noise and interference in the uplink and downlink. (Errors add, rather than noise powers.) Access of this traffic to the satellite is with an FDMA arrangement. In the downlink 92 Mbps is transmitted with a QPSK signal in a 120 MHz bandwidth.

Fixed user terminals have antennas with 1.1° beams in the uplink and 1.6° beams in the downlink. The system is expected to include a large number of these earth terminals.

### **2.2 Salient Features of the IRIDIUM System**

The space portion of the IRIDIUM system consists of 66 satellites in nearly-polar circular orbits 780 km above the earth. There are 11 satellites in each of 6 orbital rings 31.5° apart in longitude. (Between one pair of rings, with satellites travelling in opposite directions at nearby longitudes, the longitudinal separation between the rings is only 22.5°.)

There are a relatively small number of rather complex feeder-link earth station complexes serving these satellites. An earth-station complex includes three earth stations, with each "end" station separated by approximately 37 nautical miles or 69 km. from the central station, as indicated in Figure 1. The "end" stations are 126 km apart. The antennas of these earth stations are steerable to track the LEO satellites. They have 0.24° beams in the uplink, and 0.36° in the downlink. There are approximately 5 such earth station complexes planned for use within CONUS.



Figure 1

A Typical IRIDIUM Earth Station Complex

The signals in the IRIDIUM feeder-link system are QPSK signals with a 6.250 Mbps data rate after 1/2 rate channel encoding , ie. with a 3.125 Mbps data rate. The signals are re-processed in the IRIDIUM spacecraft and routed to different spacecraft via inter-satellite links. As in the SPACEWAY system, this process avoids the addition of noise and interference powers in uplink and downlink. There is automatic power control (APC) in the transmitters of both the earth stations and the satellites. The EIRP of the 6.25 Mbps signal can be varied from - 22.3 dBW to + 12 dBW at an earth station, and from - 22.4 dBW to - 3.2 dBW on the satellite. This APC is intended primarily to overcome the attenuation due to rain, particularly at low elevation angles, but can also be used to mitigate the effects of interference, as discussed below.

### 3.0 Noise and Interference Budgets in the Two Networks

The measure by which noise and interference is evaluated, the system's carrier-to-noise or carrier-to-interference ratio, is discussed in Section 3.1. The noise budgets of each of the systems are discussed briefly in Section 3.2, based on a more detailed consideration of those budgets in Annex B. The worst-case interference between the two systems without site diversity being used is then discussed in Section 3.3.

#### 3.1 Carrier-to-Noise Ratio and Carrier-to-Interference Ratio as the Measure of System Performance

A number of performance criteria might be used to evaluate the seriousness of a given amount of thermal noise or interference. These are either of the interference-to-noise ratio type, or the interference-to-desired carrier type. Either may be over the complete signal bandwidth or on a per-unit-bandwidth basis.

Both systems involved in this study are digital, so the basic parameter determining their performance is their  $E_b / N_o$ , their received energy per bit to noise spectral density.  $E_b / N_o$  is related to the system's pre-detection carrier-to-noise-plus-interference ratio  $C / (N + I)$  by the simple relation

$$E_b / N_o = C / (N + I) + 10 \text{ Log ( System Bandwidth / Transmission rate) } \dots\dots\dots (1).$$

Because of this relationship, and because detailed characteristics are either known or assumed about both systems, the measure of performance used in the analyses below is single-entry  $C / N$ ,  $C / I$ , or  $C / (N + I)$  ratios. The effect of a second interference source is considered simply by adding another source of noise to the ratio  $C / (N + I_1 + I_2)$  using the standard equation

$$c / (n + i_1 + i_2) = \{ (n / c) + (i_1 / c) + (i_2 / c) \}^{-1} \dots\dots\dots (2),$$

where the terms are actual values, not dB ratios.

### 3.2 Carrier-to-Thermal-Noise Ratios of the SPACEWAY and IRIDIUM Systems

The C / N ratios in the uplinks and the downlinks of both the IRIDIUM and the SPACEWAY systems are examined in this section. Clear air conditions are assumed in this analysis, as that is the condition with a high probability of occurrence. Operation during conditions in which there is significant rain attenuation is addressed later in the paper.

The link budgets are examined when both systems have a 30° elevation angle. This is the situation with potentially the worst interference conditions, because of the longest distance between the IRIDIUM earth station and its satellite in which the two satellites are at virtually the same location as seen from both the IRIDIUM earth station and the SPACEWAY earth station.

Under those conditions, the carrier-to-noise ratios of the four links of interest are indicated in Table 2, based on detailed link budgets shown in Annex B. For the IRIDIUM system the required clear-air C / N ratios and the APC reserve is indicated. For the SPACEWAY terminals that do not use APC the actual clear-air C / N and the margins above the required clear-air C / N are indicated.

**Table 1**

**Clear-Air C / N Ratios of the SPACEWAY and IRIDIUM Systems  
In the Absence of Inter-Network Interference**

Parameter	Iridium Uplink	Iridium Downlink	Spaceway Uplink	Spaceway Downlink
Transmitted Power, dBW	- 18.7	- 18.3	- 3.5	+ 12.5
Clear-Air C / N, dB	10.7	10.7	16.8	14.5
Required Clear-Air C / N, dB	10.7	10.7	10.6	16.8
Minimum C / (N + I), dB	7.7	7.7	6.9	3.9
Margin, dB (Spaceway)	-	-	6.2	- 2.3
APC Reserve, dB (Iridium)	30.7	15.1	-	-

This table indicates that there is considerable power margin in each of the four links to absorb either rain attenuation, or interference, or a combination of the two sources of system degradation in performance. In the SPACEWAY downlink there is a supposed negative margin of 2.3 dB, but that is to provide a clear-air C / N of 16.8 dB, 12.9 dB above the minimum C / ( N+I ) necessary to provide an output signal with the required bit-error-rate (BER).

### **3.3 Carrier-to-Noise-Plus-Interference Ratios of the SPACEWAY and IRIDIUM Systems When Each is Providing Maximum Interference Into the Other**

Worst-case interference levels in the uplink path and the downlink path of both the IRIDIUM network and the SPACEWAY network are examined in this section. "Worst-case" in this situation is taken to mean when the IRIDIUM and SPACEWAY satellites are both in the boresite of the earth station antenna of the link under consideration. These interference levels are determined for two conditions:

1. when the IRIDIUM system holds its excess APC in reserve to combat attenuation due to rain, and
2. when the IRIDIUM system uses its excess APC in a dynamic fashion to combat both rain attenuation and inter-network interference.

This analysis is a prelude or a bench-mark leading to mitigation of the effects of inter-network interference when IRIDIUM earth station site diversity is also used to combat the interference.

A detailed analysis of the interference in each of the four links of interest is in the attached Annex C. A summary of the results determined in that annex, combined with the performance of each of the links without inter-network interference present, is made in Table 2 below.

As is indicated from the information summarized in Table 2, either the SPACEWAY system or the IRIDIUM system will briefly experience high levels of interference and correspondingly low  $C/(N+I)$  ratios when satellites of both systems are in the boresite of an antenna of one of the two systems. No geographical isolation of the two networks on the ground is assumed in this analysis, so it is assumed that higher interference levels would be experienced by the two networks simultaneously. Either of one of two events would take place at that time:

1. the IRIDIUM network would experience high levels of interference, perhaps observed first in the demodulator circuit of the digital 6.25 Mbps bit stream, and respond to this link degradation by increasing its transmitter powers to the limit of its APC reserve; or
2. it would not use that reserve, holding it to be used solely to combat a degradation of the link performance as a result of rain attenuation of the desired signal.

If the first alternative were to be followed, there would be enough APC reserve power to completely overcome the effects of interference from the SPACEWAY network in the IRIDIUM uplink during clear-air conditions, and almost enough in the downlink. (There would be a shortfall of about 2.2 dB, with no margin for any other degradation of the link.) This action on the part of the IRIDIUM operator would, however, cause serious interference to the SPACEWAY network, reducing the performance of that system from a comfortable positive-link-margin situation to one of serious negative margins of up to 14.7 dB in the uplink and 8.8 dB in the downlink.

**Table 2**

**Worst-Case C / (N + I) Levels and Margins in Each of the Links of Interest  
Under Various Conditions of Operation**

Noise and Interference Condition in Link	IRIDIUM APC Used to Combat Inter-Network Interference	Parameter Considered	Link			
			IRIDIUM Uplink	IRIDIUM Downlink	SPACEWAY Uplink	SPACEWAY Downlink
Thermal Noise Only	not applicable	Trx. Power, dBW	-18.7	-18.3	-3.5	+12.5
		C / N , dB	10.7	10.7	16.8	14.5
		Min. C/N, dB	7.7	7.7	6.9	3.9
		Margin, dB	3.0	3.0	9.9	10.6
Thermal Noise and Inter-Network Interference	no	Trx. Power, dBW	-18.7	-18.3	-3.5	+12.5
		C / (N+I) , dB	-14.3	-9.6	14.0	8.8
		Min. C/(N+I), dB.	7.7	7.7	6.9	3.9
		Margin, dB	-22.0	-17.3	7.1	4.9
		Available APC, dB	30.7	15.1	N/A	N/A
Thermal Noise and Inter-Network Interference	yes	Trx. Power, dBW	+ 6.3	-3.2	-3.5	+12.5
		C / (N+I) , dB	10.7	5.5	-10.8	- 4.9
		Min. C/(N+I), dB.	7.7	7.7	6.9	3.9
		Margin, dB	3.0	-2.2	-17.7	- 8.8
		Available APC, dB	5.7	0	N/A	N/A

If, instead, the IRIDIUM system operator elected to **not** use that system's APC margin to combat the increase in interference in the link, the SPACEWAY system would be relatively unaffected by interference from the IRIDIUM network, but the IRIDIUM network would suffer large negative link margins, with  $C/(N+I)$  margins too low for the system to function.

It is obvious from this brief analysis that when the satellites of the two networks are in line as seen from the earth stations of either network, either one or the other network will experience temporarily a "system outage", in that the  $C/(N+I)$  of one or the other network will temporarily be so low that the network will cease to function, and may lose bit-synchronization or frame-synchronization between its transmitter and receiver. This is obviously an unworkable situation, and requires a further interference-mitigation measure to be utilized if the two networks are to be able to share spectrum.

#### **4. Use of Earth-Station Site Diversity to Mitigate the Interference Between the Two Networks**

As explained in Section 3 above and illustrated in Table 2, when the SPACEWAY and the IRIDIUM networks share the same frequency band and there is no isolation between the two networks due to geographical separation, there is transient harmful interference into one or the other of the two networks. Specifically, if the IRIDIUM network operator elects to **not** use the excess APC power available to him to mitigate interference into his own network when the satellites are in-line at a  $30^\circ$  elevation angle, the minimum elevation angle of a SPACEWAY system serving CONUS, his network would suffer harmful interference in both the uplink and the downlink. It would suffer a worst-case clear-air transient negative  $C/(N+I)$  margin of about -22 dB in the uplink and about -17 dB in the downlink. If that mode of operation were followed by the IRIDIUM system the SPACEWAY system would **not** suffer harmful interference; its worst-case transient  $C/(N+I)$  margin would be about +7 dB in the uplink and about +5 dB in the downlink.

If, instead, the operator of the IRIDIUM system decided to use the excess APC power available to him to mitigate the interference to the extent possible, he could increase his earth-station power by 25 dB of an available reserve of 31 dB to provide a +3 dB interference margin in the uplink, and increase the power of the satellite by the total available amount of 15.1 dB to achieve a transient negative margin of only -2 dB. In that event the SPACEWAY system would be the one to suffer harmful interference; its uplink  $C/(N+I)$  margin would be about -18 dB as a result of the 25 dB increase in IRIDIUM uplink EIRP, and its downlink would suffer a negative margin of about -9 dB.

Thus the use of IRIDIUM APC alone as an interference mitigation measure would transfer the problem from one network to the other, but would be no closer to enabling shared use of the spectrum by both networks. It is shown in this section, however, that by combining the correct use of APC in the IRIDIUM network with judicious site selection of the earth stations of an IRIDIUM earth station complex, harmful interference can be avoided in both networks. It should be noted that in this consideration "harmful interference" is taken to mean a worst-case transient  $C/(N+I)$  in either link of either network less than +3 dB.

To get out of the loop of either one network or the other suffering harmful interference whatever

power levels are chosen in either network, it is necessary to obtain isolation between the two networks through the discrimination properties of one or more of the four antennas involved, either the earth station or the satellite antenna of either the SPACEWAY or the IRIDIUM network. The beamwidths of these four antennas, a measure of their discrimination capability, are indicated in Table 3 ( Table D.1 of Annex D).

**Table 3: Antenna Beamwidths**

Antenna	Beam Size In the Uplink	Beam Size in the Downlink
IRIDIUM Satellite	5.0 °	7.4°
IRIDIUM Earth Station	0.24°	0.36°
SPACEWAY Satellite	1.0 °	1.1°
SPACEWAY Earth Station	1.1°	1.6 °

Because the IRIDIUM earth station has a much smaller beamwidth and so better discrimination capabilities than any of the other three antennas, and because there are three antennas in an IRIDIUM earth-station complex that could possibly be used to reduce interference in one or the other, or both, of the two networks, use of this antenna is addressed below, combined judiciously with the use of the available IRIDIUM system's excess APC.

#### **4.1 Mitigation of Uplink Interference through Use of Earth-Station Site Diversity**

Let us consider first the IRIDIUM uplink. We know that with a low uplink power, just enough to raise the  $C/N$  ratio to an acceptable level at a 30° elevation angle, its  $C/(N+I)$  would be about 22 dB below its minimum value of 7.7 dB. The only options to avoid interference from transmitting SPACEWAY earth stations is to increase its uplink power or use its satellite antenna discrimination to avoid the interference. This latter option results in large exclusion zones by one network or the other, and so is avoided. The only option is to raise the IRIDIUM earth station's power level. Let us suppose that this is raised the full 25 dB discussed earlier.

We know from the above discussion that this makes the SPACEWAY uplink unworkable if the SPACEWAY earth stations are effectively co-located with the IRIDIUM earth station, ie. if there is no SPACEWAY satellite antenna discrimination brought into play. Suppose, however, that we can cause the IRIDIUM earth station antenna to not point directly at the SPACEWAY satellite during a so-called "interference event". This would require physically moving the earth-station antenna, or using another one during the time that the "primary" antenna is involved in the transient "interference event". Analysis described in Annex D indicates that it could reduce its interference into the SPACEWAY satellite to a non-harmful level, and thereby permit use of the band by both systems, if the second antenna is pointed **0.313° away from the SPACEWAY satellite** while it is pointing directly at its IRIDIUM satellite. At the minimum 30° elevation angle assumed for the SPACEWAY system in CONUS the required distance that the earth station would have to be moved,

or a second one used in its place, would be **at least 8.5 km and not more than 17.0 km**, depending on whether is moved perpendicular to or in the same azimuthal direction as the satellites. Doesn't seem excessive. Thus

*the worst-case uplink interference in both networks can be reduced to non-harmful levels simply by using a combination of the available uplink APC power in the IRIDIUM earth station and having the ability to choose either of two IRIDIUM earth stations not less than 17 km apart during a given IRIDIUM satellite "pass" in which there is a possibility of harmful interference.*

## **4.2 Mitigation of Downlink Interference through Use of Earth-Station Site Diversity**

Simultaneous mitigation of interference in the two networks through use of site diversity is considered now for the downlinks of the two networks. The process is similar but analytically more complex than in the uplink.

In this direction of transmission let us begin our discussion with the situation in which maximum satellite APC is used to attempt mitigation of interference in the IRIDIUM downlink. (There was almost, but not quite enough reserve power to reduce the downlink interference in the IRIDIUM downlink to an acceptable level; perhaps in a follow up satellite design there would be, all other things being unchanged. However, as shown below, this is not necessary.

Let us begin our quest for mutually successful use of the same band by not requiring any separation between SPACEWAY and IRIDIUM earth stations ie. not requiring any satellite antenna discrimination, but rather to correct the negative margin in the SPACEWAY downlink by reducing the IRIDIUM satellite power, ie. by putting some of the satellite APC back in reserve. Let us, in fact, reduce it by 11.8 dB in order to raise the SPACEWAY downlink  $C / (N+I)$  to 3 dB above its minimum value of 3.9 dB. Fine, but now the IRIDIUM downlink is really in bad shape; it was already 2.2 dB below its minimum permissible value, and now is 14 dB below that minimum value.

Let us now correct what we have just done, and more, by improving the IRIDIUM downlink  $C/(N+I)$  by 17 dB, to 3 dB above its minimum permissible level, without in any way degrading further the SPACEWAY downlink performance. This can be done, as in the uplink case, by choosing an alternate IRIDIUM earth station with 17 dB isolation from the direction of the interfering SPACEWAY satellite, while of course looking directly at the IRIDIUM satellite. As discussed in more detail in Annex D, this requires that the IRIDIUM earth station antenna be pointed  $0.44^\circ$  away from the SPACEWAY satellite. As discussed in Annex D, this can be done by having an alternate IRIDIUM earth station available at least 12 km away under the best azimuthal conditions, and not less than 24 km away under the worst such conditions. These are larger required separations than those encountered when considering the uplink, primarily because of the larger antenna beamwidth in the downlink, ie. a lower  $D/\lambda$  ratio at the lower frequency. However, it can be concluded that

*the worst-case downlink interference in both networks can be reduced to non-harmful levels simply by lowering the use of downlink transmitter power in the IRIDIUM satellite to -15 dBW*

*and having the ability to choose either of two IRIDIUM earth stations not less than 24 km apart during a given IRIDIUM satellite "pass" in which there is a possibility of harmful interference.*

The same IRIDIUM earth station would presumably be used at any one time in both uplink and downlink. Thus the separation distance between the two alternate earth stations would have to meet both uplink and downlink separation conditions, ie be not less than 24 km apart, the larger of the 17 km uplink and the 24 km. downlink requirement.

#### **4.3 Mitigation of Interference through Use of Earth-Station Site Diversity if the APC Reserve in the Iridium System Is Not Used**

The above discussion in Sections 4.1 and 4.2 of the paper consider the potential to mitigate interference in both networks through complementary use of both earth station diversity and increased power of the IRIDIUM transmitters. This increased power is available in the system as an APC reserve to combat periodic rain attenuation. In this section the ability to use earth-station diversity as a measure to mitigate interference if APC is **not** also simultaneously used. The possibility is analyzed in detail in Section D.5.2 of Annex D of this paper.

##### **4.3.1 Mitigation of Uplink Interference**

Mitigation of uplink interference is **not** possible if use of the available APC power to avoid interference is not simultaneously used. This is because the application of earth-station diversity in the uplink requires that the IRIDIUM system is the interfering network, not the interfered-with network, before the earth-station diversity technique is applied. The only alternative is the use of the IRIDIUM spacecraft's antenna isolation to avoid interference from SPACEWAY earth stations. This is basically an unworkable arrangement, in that it requires large exclusion zones between where one and where the other network can install earth stations. This is considered to be operationally unworkable, and is written off as a technique to consider further in this paper.

##### **4.3.2 Mitigation of Downlink Interference**

Assuming that uplink interference is mitigated as discussed in Section 4.1 above, mitigation of downlink interference through the use of earth-station diversity alone may be feasible, as discussed here and in Section D.5.2.2. Without the use of APC reserve power in the spacecraft to mitigate interference, the SPACEWAY system would have a downlink  $C / (N+I)$  of 8.8 dB, 4.9 dB above its minimum value, but the IRIDIUM system would have a  $C / (N+I)$  of -9.6 dB, 20.3 dB below the minimum operational value of 10.7 dB. To correct this deficiency through the use of earth-station diversity a 20.3 dB deficiency in link performance must be overcome. To do this through the discrimination IRIDIUM's earth-station antenna requires that the antenna's gain be in the sidelobe region with a gain-envelope  $32 + 25 \text{ Log}(\phi)$ . The required separation angle  $\phi$  in this case is  $0.92^\circ$ . The required separation distance between the IRIDIUM earth stations to carry out this measure when the satellite elevation angle is  $30^\circ$  is at least 25 km, and may be as large as 50.1 km.

#### **4.4 Summary of the Use of Earth-Station Diversity as An Interference-Mitigation Technique**

The use of two or more IRIDIUM earth stations to avoid interference between IRIDIUM and SPACEWAY systems is shown above to be a very effective method if used in concert with appropriate use of APC reserve power in the IRIDIUM network. When the elevation angle of the GSO SPACEWAY satellite is not less than  $30^\circ$ , the situation if SPACEWAY were to be used to serve CONUS, the required separation between the two earth stations would not exceed 24 km. If APC were used only in the uplink, ie. in the IRIDIUM earth stations, the required separation between the earth stations would be larger, but would not exceed 50.1 km.

An IRIDIUM earth station complex is expected to include three earth stations, as shown in Figure 1 above. The separation of those earth stations is at least 69 km, with the separation between the two extreme stations being 126 km. These distances are greater than the above required separations. Thus

*IRIDIUM earth stations in their already-planned locations can be used to implement the interference-mitigation measure described above, without any re-deployment of those earth stations.*

Analysis in Section D.6.3 indicates that when the IRIDIUM path does not place that satellite in a direct line between the earth stations and the GSO SPACEWAY satellite, but between it and one of the other earth stations, this may have increased the required separation distance if there were only two IRIDIUM earth stations employed in an earth-station complex. However, there are three earth stations. This in fact eases the separation requirements in most cases, and in so doing increases the positive interference margins in both networks.

Thus, in summary, IRIDIUM earth stations can be employed in an effective interference-mitigation measure in concert with use of the APC reserve power in the IRIDIUM network. Complementary use of the APC reserve power in the earth stations is necessary for the technique to be successful. Use of a small amount of APC reserve power in the IRIDIUM satellites improves the technique in that smaller earth-station separations is possible when it also is used, but separations not exceeding that of IRIDIUM earth stations in their presently-planned arrangement is possible even if satellite APC reserve power were not used.

#### **5. Consideration of Related Factors**

It has been shown in the above discussion that a combination of IRIDIUM earth-station diversity and the judicious use of the IRIDIUM system's APC reverse power can reduce the interference in both networks to non-harmful levels even during brief interference "hits" involving satellites of both networks. However, there are several related factors that should be examined before it can be said that it is a widely usable technique. These are:

1. what is the complexity of the measure from an operational perspective;
2. how does the measure perform in an environment in which there are a large number of GSO satellites in operation in that part of the GSO in question;
3. how is this technique complementary to the use of APC reserve power to provide protection against heavy rain attenuation; and
4. what is the justification for the large interference levels in both systems before that interference is said to be "harmful" in either network;
5. how does this technique function when the elevation angle to the GSO satellite is small.

Each of these matters is addressed below in this section.

### **5.1 Operational Considerations in the Application of the Measure**

The question addressed here is

*How would the earth-station diversity measure be carried out at a given IRIDIUM earth-station complex ?*

In more precise language, how would the earth-station complex's operator know which of his three earth stations to use at any one time to avoid harmful interference from satellites on the GSO, and would the required activity include rapid transfer from one earth to the other as the "active" earth station ?

Firstly, it is assumed that those responsible for the space portion of the IRIDIUM network would know or could calculate the location of each of their 66 satellites at any one time. As well, they would know or could find out the GSO location of each of the Ka-band GSO satellites within less error than  $0.1^\circ$ , and would know or could find out the areas on the ground where those satellites would have a significant pfd. This information in composite would comprise a sufficient "data-base" to determine what IRIDIUM satellite would be involved in an interference "hit", and on what "pass" of that satellite at a given earthy station. There need not be any "surprises", this information can all be determined well in advance of the actual pass of a given IRIDIUM satellite at a given earth station. Further, by straight-forward trigonometry it could be determined which one of the three earth stations would be involved in a harmful-interference "hit" if it were used, and so which one to be used on that pass to most effectively avoid that harmful interference. This information could be translated into a set of daily or weekly instructions to the operator of a given earth-station complex on which earth station to use on which satellite pass.

There would be no need as part of this operation to rapidly switch from one earth station to another during a pass, except for the occurrence of heavy local rain at one of the sites. But that switch would be due to the rain, not to the earth-station-diversity measure. Thus it is concluded that calculations

would be necessary to determine in advance which earth station to use at a given site at a given time, but this can all be determined in advance, and need not be the cause of any rapid transfer from one earth station to the other of a given earth station site.

These requirements may have to be combined with the requirement to track more than one IRIDIUM satellite at a given site, particularly in higher-latitude regions. However, there is nothing to indicate that the measure could not be carried out for the prime satellite at that location at the time of a potential interference "hit".

## **5.2 Performance of the Measure In an Environment of a Closely Packed GSO**

The above analysis was done on the assumption that there was only one GSO satellite involved. However, there may be several GSO satellites in the part of the GSO arc of interest. For instance, SPACEWAY satellites are planned for implementation at  $99^{\circ}$  W and  $101^{\circ}$  W, at  $2^{\circ}$  spacing. There may be other satellites a further  $2^{\circ}$  away serving the same or a similar service area.

One fortunate characteristic of the IRIDIUM system is that its satellites are in approximately polar orbits, ie. they fly in approximately a north-south direction when crossing the orbital plane or the line joining the GSO satellite and the IRIDIUM earth station in question. This maximizes the separation angles between the IRIDIUM satellite and GSO satellites neighbouring the GSO satellite involved in the interference "hit", and so minimizes the increase in interference into the IRIDIUM system due to aggregate effects of being near several GSO satellites.

In the uplink, the IRIDIUM satellite avoids interference simply by increasing the EIRP in its own earth station so that without site diversity it is the interferer rather than the interfered-with network. Site diversity is then employed to use the discrimination of the IRIDIUM earth station antenna to avoid interference into the GSO satellite. The separation angle need be only in the order of  $.313^{\circ}$ , nowhere near the estimated  $2^{\circ}$  away of the neighbouring satellite. Thus there is no aggregate interference effect in the uplink, and so no uplink problem associated with operating in an environment of closely placed GSO satellites.

In the downlink earth station diversity is used to protect both systems. There would be no aggregate interference into the GSO system due to sharing with the non-GSO system, beyond the normal aggregate-to-single-entry increase in interference among the GSO satellites. However, that is a separate issue and can be accommodated separately, if necessary by a slightly wider separation between GSO satellites. This steady-state interference, however, is usually small compared to the thermal noise of the GSO system, and would not markedly influence the interference budgets in Annexes C and D and in Table 2.

The main concern, then, is the potential interference into the downlink of the IRIDIUM system due to the close (?) proximity of neighbouring GSO satellites. If the APC power reserve in the IRIDIUM satellite is **not** used to aid in the mitigation of interference in the two networks, angular separations of about  $0.92^{\circ}$  would be necessary. Thus, in the worst case, a second GSO satellite may be only  $1.08^{\circ}$  away. This may increase the interference in the IRIDIUM downlink by about 2.2 dB.